10.—MARINE JURASSIC OF EAST INDIAN AFFINITIES AT BROOME, NORTH-WESTERN AUSTRALIA.

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ABSTRACT.

Artesian bores at Broome, North-Western Australia, have disclosed the existence of a series of strata of Jurassic age at depths ranging probably from about 950 feet to at least 1,550 feet. The following fossils have been obtained from various depths between approximately 1,170 and 1,300 feet: *Buchia subspitiensis* (Krumbeck), *Buchia subpallasi* (Krumbeck), *Belemnopsis* cf. *alfurica* (Boehm), and *Belemnopsis* cf. *incisa* (Stolley). This assemblage seems to correspond most closely to that of the "Aucellen-Sandstein" of the island of Misool. The relationships of the Australian fauna to contemporaneous faunas of the Timor-East Celebes geosyncline, of the Himalayas (Spiti shales), and of New Zealand (Kawhia Harbour) are discussed and the fossils are described.

INTRODUCTION.

During Jurassic time Australia experienced a continental period with deposition of terrestrial and lacustrine sediments over wide areas in different parts of the country. Marginal parts, bordering the shield in Western Australia, were, however, affected by marine transgressions of which the one that has left its traces in the Geraldton district has been known for a long time. Spath has recently (1939) from a study of the ammonoid fauna of this transgression correlated the Geraldton strata with the *sauzei* zone of the European Bajocian but he states that the fauna is of a somewhat isolated character.

That this Bajocian transgression in Western Australia reached beyond the limits of the Geraldton district, where the main exposures of the strata occur, was indicated by me in 1940, when I described an occurrence of strata of presumably the same age from the Minilya River, North-West Basin, approximately 450 miles north of Geraldton. It is not unlikely that the Bajocian sea in Western Australia transgressed along an extensive belt, but that its

deposits are now either inaccessible or have been removed by erosion. In that paper the discovery was announced of Jurassic strata of different age in the northern part of the Westralian Geosyncline. The study of the fossils from these strata has now been completed and preliminary remarks on the fauna have already been published in another paper (Teichert 1939).

As early as 1919 Maitland (p. 41) mentioned the occurrence of belemnites in one of the Artesian bores (No. 2) at Broome, North-western Australia, at a depth of 1,300 feet below sea-level. From this he inferred the presence of strata of either Jurassic or Cretaceous age in this region. On later geological maps the area was shown as Jurassic, and Clapp discussed (1926, p. 1129) the possible extension of these strata into the Desert Basin. Since the appearance of Maitland's summary in 1919, additional bores, particularly No. 3, have brought to light more fossil specimens and it is now possible to determine the age of these fossiliferous strata below Broome and their palaeogeographic relationships.

During a visit to Broome in June, 1939, Mr. B. E. Bardwell kindly showed me a specimen of a belemnite which had been obtained from one of the artesian bores there. As this specimen was not related to any belemnites so far known from Western Australia, my interest was aroused and inquiries regarding further fossils from the bores were made. Mr. H. A. Ellis, Acting Government Geologist, and Mr. Crawford, who had been in charge of the boring operations, very kindly assisted in collecting the necessary information, and Mr. Ellis also placed at my disposal the specimens which are now kept in the collections of the Geological Survey of Western Australia. To all these gentlemen I wish to render my sincere thanks for their valuable help. The plate has been prepared by Mrs. Gertrude Teichert. I also wish to thank Professor E. de C. Clarke for careful reading and valuable criticism of the manuscript.

THE STRATA AND THEIR FAUNA.

Four artesian bores have been put down within the limits of the township of Broome, all of them starting at approximately the same height, not much above sea-level. Until a depth of round about 950 feet a series of sands or loosely cemented sandstones interbedded with a few conglomeratic layers was penetrated. Below this sandy series a layer of grey or dark blue shale was struck and shaly strata predominate below this level. The actual depths at which the first shale layer was struck are:—

963 feet in bore No. 1
920 feet in bore No. 2
960 feet in bore No. 3
935 feet in bore No. 4

It would appear, therefore, that the surface of the shale is slightly undulating. The thickness of this uppermost shale layer in bores No. 1 and 3 is 10 and 11 feet respectively and in both bores it is underlain by 3 feet of hard sandstone. This sandstone band seems to be missing in bore No. 4, and no accurate log is available for these levels in bore No. 2. The log of bore No. 3 is reproduced here in Table I as fairly representative for the section. Shales with occasional intercalations of greensand and limestone constitute most of the section below 960 feet.

TABLE I.

Log of Artesian Bore No. 3 at Broome.

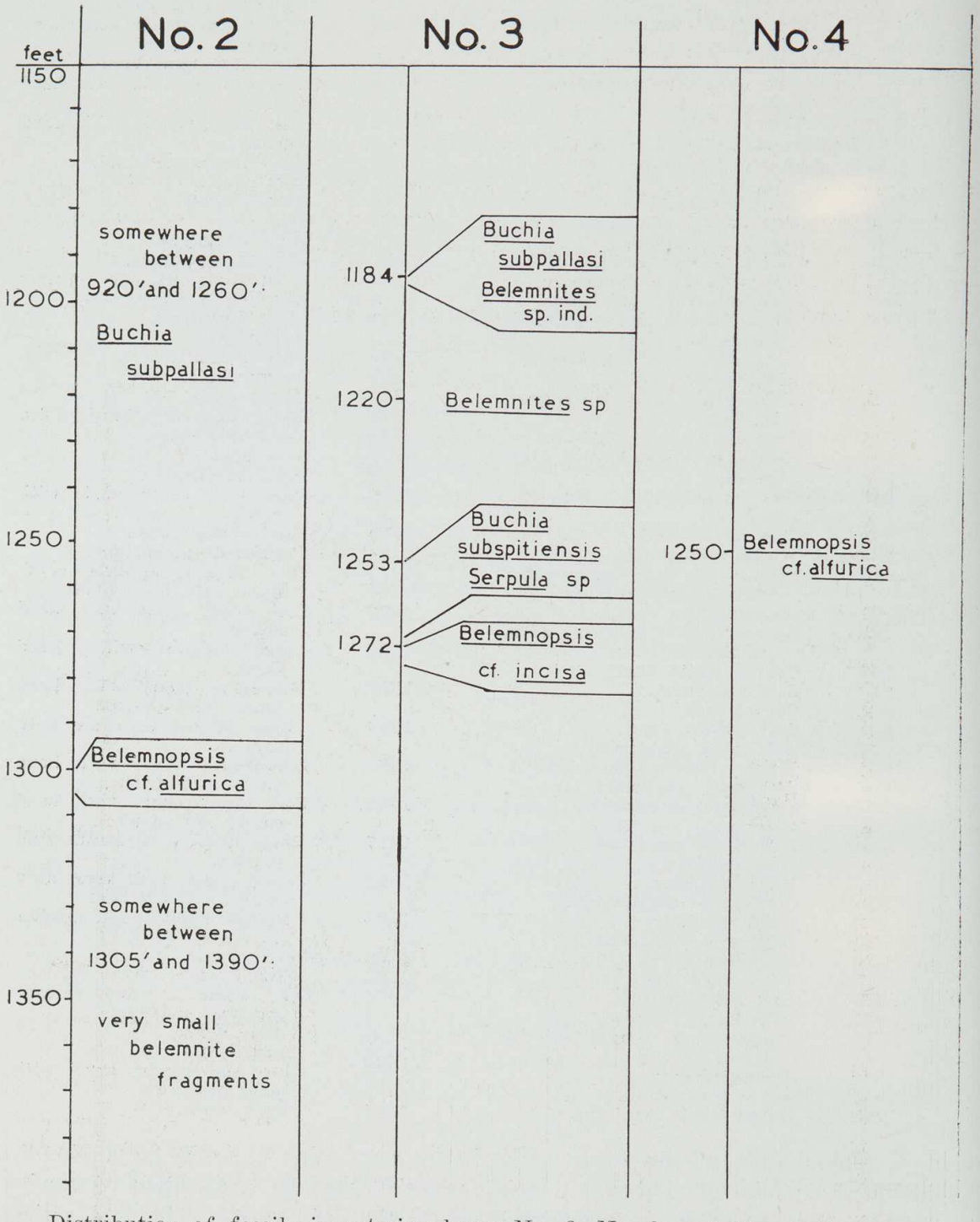
Depth from surface Feet		Depth from surface. Feet	
47	Red sandy loam getting lighter in colour.	1120	Grey puggy shale with hard nodules and pyrites.
102	Soft grey sandstone, hard in places.	1158	Grey puggy shale with hard knobs.
112	Soft grey and yellow sandstone, hard in places.	1159	Hard limestone band.
143	Yellow sand.	1161	Grey puggy shale with hard knobs.
200	Yellow sand.	1184	Grey puggy shale with hard knobs.
218	Yellow sand.	1185	Hard limestone band.
246	Coarse grey sand with hard knobs.	1189	Grey shale.
285	Soft grey sandstone.	1190	Hard limestone.
300	Soft brown sandstone.	1200	Grey shale.
316	Brown sandstone.	1200 6″	Hard limestone.
320	Coarse brown sand.	1211 6″	Grey puggy shale.
411	Very soft grey sandstone.	1212	Hard limestone.
442	Very soft grey sandstone.	1215 6″	Grey puggy shale.
454	Coarse brown sand with hard knobs.	1216	Hard limestone.
470	Very soft grey sandstone.	1220	Puggy shale.
480	Light pink sand.	1221	Hard limestone.
527	Light pink sand with grey bands.	1223	Puggy shale.
534	Grey sand.	1230	Puggy shale.
536	Coarse grey sand with clay bands.	1242	Puggy shale with hard knobs.
548	Red sand with ironstone nodules.	1243	Hard sandstone.
581	Grey drift sand.	1252	Grey shale.
623	White drift sand.	1253	Hard sandstone.
640	White drift sand with water worn quartz pebbles.	1270	Dark grey sandy shale with shells.
741	Coarse white sand.	1272	Hard sandy shale.
743	Coarse sand with water worn pebbles.	1274	Fossilized greenstone.
763	Coarse white sand.	1275 6″	Very hard crystallised sandstone with hard knobs.
813	Soft red sand.	1296	Soft sandy shale with hard knobs.
814	Gravel bed.	1302	Sandy shale with hard knobs.
849	Soft yellow sand.	1357	Micaceous shale with hard knobs and pyrites.
856	Soft grey sandstone.	1386	Puggy micaceous shale with pyrites.
857	Hard grey sandstone.	1397	Soft sandy shale with hard knobs and pyrites.
867	Soft grey sandstone.	1405	Soft sandy shale with hard bands and pyrites.
868	Hard grey sandstone.	1417	Shale with hard bands and pyrites.
909	Soft grey sandstone.	1424	Sandy shale with very hard bands and pyrites.
914	Soft grey sandstone.	1427	Very hard bands and pyrites in sandy shale.
938	Grey sandstone.	1432 6″	Sandy shale.
939	Hard sandstone.	1433	Dark band.
950	Soft grey sandstone.	1436 6″	Very hard country (coarse grained sandstone).
953	Hard sandstone.	1440	Puggy shale.
960	Soft grey sandstone.	1444	Puggy shale.
971	Grey shale.	1461	Fine and coarse sand with good water.
972	Very hard band.	1464	Puggy shale.
979	Soft grey shale.		
1001	Fine sandy shale.		
1040	Puggy shale, very soft in places.		
1042	Puggy shale.		
1043	Very hard band.		
1056	Puggy shale with pyrites.		

The depths of the other three bores are:—No. 1, 1,459 feet; No. 2, 1,775 feet; No. 4, 1,476 feet. It is noticeable that the proportion of sandy strata increases with greater depths and in the deepest bore, No. 2, a series of "white sand and boulders" was encountered between 1,555 and 1,773 feet.

The Jurassic fossils described in this report have been brought up from bores 2, 3 and 4 from between 1,184 and 1,390 feet (see Table II) and on account of the lithological uniformity of the strata from the top shale layer down to about 1,500 feet it may be assumed that the entire series from about

950 to 1,500 feet is of Jurassic age. The sands and sandstones above the top shale layer are uncemented or very loosely cemented, glauconite is absent from these strata, and they contain no macrofossils. This series is unlike

TABLE II.



Distribution of fossils in artesian bores No. 2, No. 3, and No. 4, Broome, North Western Australia.

any known series of strata of Cretaceous age in Western Australia and is, therefore, thought to be younger. Cretaceous thus seems to be absent from this section. As to the sandy series in bore No. 2 below 1,500 feet, no indication of its age can be given.

The fauna is characterized by an association of species of *Buchia* with belemnites of the group of *Belemnopsis gerardi* Oppel. This assemblage is highly characteristic of late Middle to early Upper Jurassic strata in the Himalayas, the East Indies, and in New Zealand. The most important species of the Broome assemblage are:—

Buchia subspitiensis (Krumbeck).
Buchia subpallasi (Krumbeck).
Belemnopsis cf. *B. alfurica* (Boehm).
Belemnopsis cf. *B. incisa* Stolley.

The vertical distribution of these species can be seen in Table II. Although *Buchia subpallasi* in bore No. 3 occurs at a higher level than *B. subspitiensis*, these two species cannot be considered as good horizon-markers. In certain facies on Misool both species have been found together in the same stratum, and I will, therefore, here speak of this fauna as of the *subspitiensis-subpallasi* assemblage.

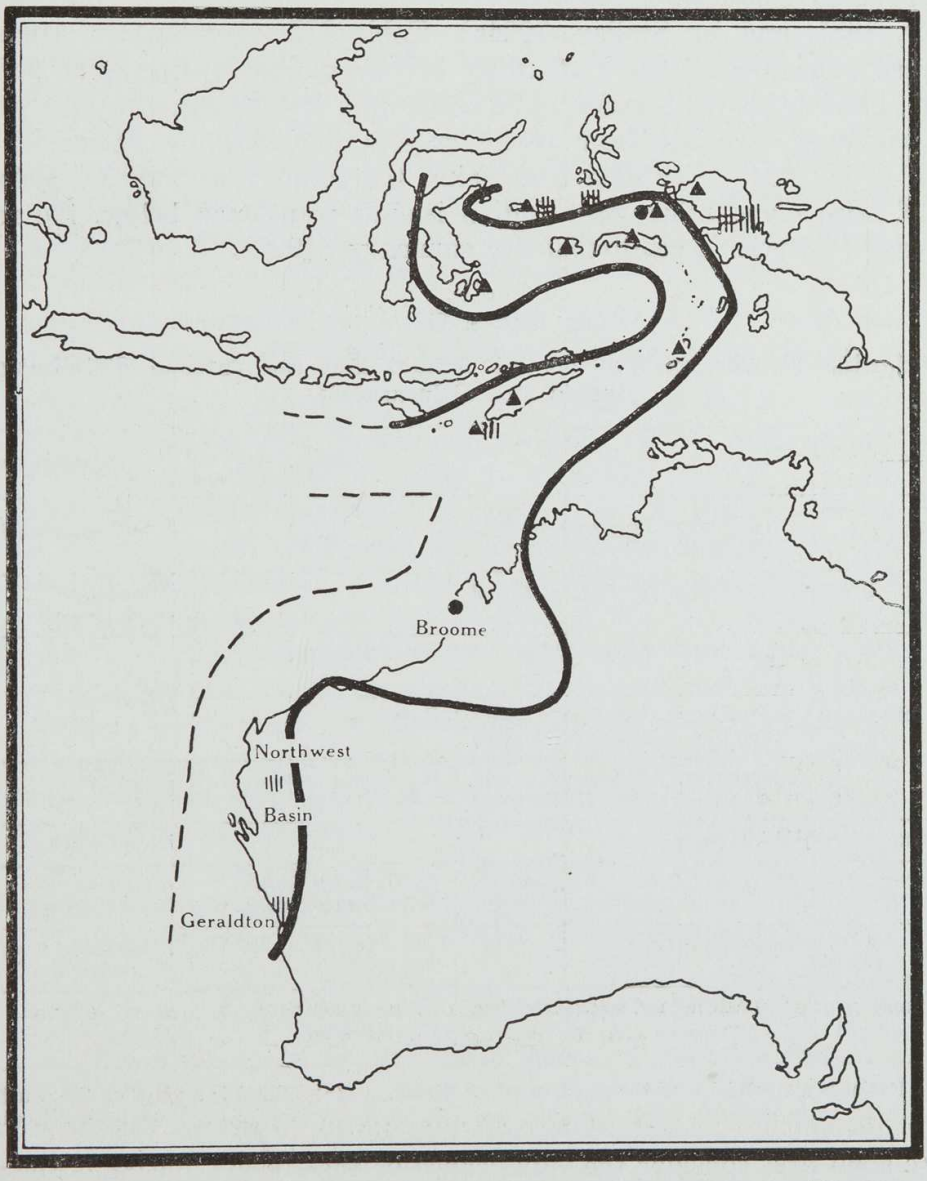


Fig. 1.—Map of part of Australia and the East Indian Archipelago, showing ▲ occurrences of *Buchia malayomaorica*, ● occurrences of *Buchia subspitiensis* and *B. subpallasi*, and |||| distribution of marine Bajocian.

AGE AND PALAEOGEOGRAPHIC RELATIONSHIPS OF THE FAUNA.

Contemporaneous faunas have a wide distribution in the Himalayan-Australasian realm and our knowledge of them is due to a number of workers, including Uhlig, Holdhaus, Wanner, Krumbeck, Stolley, Zittel, Boehm, Trechmann, and Marwick. As may be expected, the relationships of the new Australian fauna are closest with that of the East Indies, particularly with that of the Timor-East Celebes geosyncline (Umbgrove, 1938), where rocks containing *Buchia* and belemnites of the group of *Belemnopsis gerardi* are found from Rotti and Timor in the south to Misool in the north (fig. 1). Contemporaneous deposits with either *Buchia* or belemnites of the *gerardi* group are also known from the eastern and northern borderland of the geosyncline, viz., from the Vogelkop on New Guinea (Broili, 1924), and from the Soela islands, Mangola and Taliaboe (Boehm, 1905, 1907). The most complete section is at present known from Misool and neighbouring islets where the field relations have been worked out by Boehm (1910) and by Wanner (1910), and more recently by Weber (communicated in papers by Wanner, 1931, and by Stolley, 1934a). Table III represents a somewhat condensed summary of the Oxfordian to Neocomian stratigraphy and the vertical distribution of species of *Buchia* and *Belemnopsis* in this region which has been compiled from recent papers published by Krumbeck and by Stolley in 1934. For data concerning the geology as well as geological maps of Misool and other East Indian islands mentioned below, the reader is referred to Rutten's comprehensive summary (1927).

TABLE III.

The Oxfordian-Neocomian sequence of Misool and the vertical distribution of *Buchia* and *Belemnopsis*.

——	——	*Buchia*.	*Belemnopsis*.
Neocomian	Upper Fatjet limestone of Fatjet (1) and Misool	....	*B.* cf. *tanganensis*
Neocomian - Upp. Jurassic	Lower Fatjet limestone of Misool	....	*B. misolica* *B.* cf. *gerardi*
Upper Oxfordian	Uppermost Fatjet shale of Fatjet	*B.* cf. *subspitiensis*	*B. gerardi*
	Inoceramus limestones and marls = Upper Fatjet shale	*B.* sp.	
	Inoceramus limestones and marls = Lower Fatjet shale	*B. malayomaorica* (in lower part)	*B. gerardi*
Middle Oxfordian	Lilintá marls	....	*B. moluccana*
Upp. Lower Oxfordian	Marly limestones of Lilintá (2)	*B.* cf. *subspitiensis* *B.* cf. *subpallasi*	*B. indica* *B. moluccana*
Lower and middle Lower Oxfordian	Demú limestone	....	*B. alfurica*, *B. incisa* *B. indica*, *B.* cf. *indica*
	" Aucellen-Sandstein " and tuff	*B. subspitiensis* *B. subpallasi*	*B.* cf. *alfurica* *B.* cf. *incisa*

(1) Fatjet is a small islet off the south coast of Misool. (2) Lilintá is a place on the south coast of Misool.

We shall first consider the significance of the *Buchia* species. For many years Zittel's early description in 1864 of a find of *Buchia* (*"Aucella plicata"*) from Kawhia Harbour, New Zealand, was the only recorded occurrence of this genus in the Indo-Pacific region which still puzzled Pompeckj in 1901.

We know now, thanks mainly to the work of Holdhaus, Krumbeck, Boehm, Trechmann, and Marwick, that dense populations of *Buchia* existed in the eastern Tethys during late Middle and early Upper Jurassic time.

Two important *Buchia* assemblages have been recognised in the sequence on Misool, viz. (1) the *subspitiensis-subpallasi* assemblage of the "Aucellen-Sandstein"* and (2) the *malayomaorica* assemblage in the lower part of the *Inoceramus* limestones and marls. This latter assemblage has the wider distribution in the East Indies where it is known from Timor, Rotti, Jamdena, Ceram, Boeroe, the Soela islands, Misool, Boeton, and the Vogelkop, New Guinea (see Wandel, 1936, p. 461), but, unlike the *subspitiensis* assemblage, it is absent from the Himalayan region. On the other hand, *Buchia malayomaorica* is also represented in New Zealand. In 1911, Boehm referred certain forms from Kawhia Harbour to "*Aucella plicata*" and Trechmann (1923) retained this name for the same group, but Marwick (1926), realising important differences from typical *Buchia plicata*, renamed these fossils *Aucella boehmi*. However, Krumbeck (1923) and again Wandel (1936) pointed out that this New Zealand species is apparently identical with *Buchia malayomaorica* which has priority. Further proof of the identity of the two species is given by the fact that Marwick included one of Broili's (1924) "*Pseudomonotis*" from the Vogelkop, New Guinea, in *Buchia boehmi* and that the same specimen was identified as *Buchia malayomaorica* by Wandel in 1936. Dr. J. Marwick kindly sent me a few specimens of *Buchia boehmi* from Kawhia Harbour and I was thus in a position to convince myself of the identity of this species with *Buchia malayomaorica*.

Buchia malayomaorica has not yet been found in Western Australia, but it is by no means unlikely that it will be discovered in the future.

In New Zealand (Marwick 1934), the strata with *Buchia malayomaorica* are overlain by strata with *Buchia plicata* Zittel (1864), redescribed by Marwick in 1926 and by Wandel in 1936. In 1934 Marwick (p. 949) stated that the succession *B. malayomaorica* (= *boehmi*) — *B. plicata* illustrated very well the developmental tendencies of the genus elsewhere, viz., "obliteration of the radial ornamentation, concentric rippling of the shelly layer, involution of the umbo in the left valve, flattening of the right valve" as expressed by Holdhaus in 1913. Some of these evolutionary trends had already been described by Pompeckj in 1901. In the Boreal province the more advanced stage in the development of *Buchia* is represented by such species as *B. bronni* and *B. pallasi* which are considered by Krumbeck to be very closely related to *B. subspitiensis* and *B. subpallasi*. *B. plicata* is the equivalent representative in New Zealand.† This was also realised by Krumbeck in 1934 when he wrote (p. 435): "Der *subspitiensis*-Horizont dürfte auf Neuseeland vertreten sein durch Trechmann's *Aucella spitiensis* Holdh. und *A. blanfordiana* (Stol.) Holdh." He had, however, overlooked the fact that

*According to Krumbeck (1934) Wanner's "Aucellen-Sandstein" series is made up of alternating layers of siliceous marls and calcareous sandstones. *Buchia subpallasi* seems to be confined to the siliceous marls, whereas *B. subspitiensis* is found in both rock types. For the sake of brevity I shall adhere to Wanner's original designation "Aucellen-Sandstein."

†The holotype of *Buchia plicata* Zittel (see Wandel, 1936, pl. 15, figs. 7a, b) is very similar to *B. subspitiensis* in the obliquely truncated anterior margin of the left valve, but differs in the much stronger curvature of the umbo. The specimen figured by Marwick (1926) on pl. 71, fig. 8, is similar to the holotype except for its greater width of the anterior portion. The specimen figured by the same author on pl. 71, fig. 9, has a rather acute umbo and resembles more closely *B. subpallasi* with which it might even be identical. Kruizinga's opinion (1926, p. 18) of the identity of *B. plicata* with *B. malayomaorica* is not supported by the facts.

Marwick had shown that the specimens thus identified (with reservation) by Trechmann were identical with the typical *Buchia plicata* (Zittel) and that they came from younger beds than *Buchia malayomaorica* (= *plicata* Boehm, not Zittel, = *boehmi* Marwick).

Whereas in New Zealand, as could be normally expected, the more advanced *plicata* assemblage follows upon the more "archaic" *malayomaorica* assemblage, in Misool we are confronted with the remarkable fact that the more advanced *subspitiensis-subpallasi* assemblage is found in strata considered to be well below the strata with *B. malayomaorica*. Realizing the fact that *B. subspitiensis* and *B. subpallasi* show more advanced features than any other species of *Buchia* of Oxfordian age, Krumbeck even suggested that the Aucellen-Sandstein of Misool might be of Kimmeridgian age, although general stratigraphical evidence (see Wanner, 1931) seemed against such a determination. On the strength of the belemnites Stolley (1934a) correlates the sequence from the Lilintá marls to and including the Fatjet shales with the Wai Galo fauna of Taliaboe which is of Divesian (Mesoxfordian) age (see Spath, 1933, p. 872), but since he draws the Dogger-Malm boundary below the Aucellen-Sandstein it must be assumed that the latter, too, in his opinion, belongs to the Upper Jurassic.

The species of *Buchia* from the Spiti shales of the Himalaya (Holdhaus, 1913), especially *B. blanfordiana* and *B. spitiensis*, are closely related to the *subspitiensis* assemblage of Misool and to the *plicata* assemblage of Kawhia Harbour, but unfortunately their exact relative position in the sequence is unknown. They are, however, younger than the Belemnite beds at the base of the Spiti shales which contain species of the group of *Belemnopsis gerardi* (Uhlig, 1910) and which are considered to be of about Argovian (Neoxfordian) age. The overlying Chidamu beds in which *Buchia* apparently occurs, have an ammonite fauna which, according to Spath (1933, p. 805), is not older than Upper Kimmeridgian. The discrepancy of the determination of the age of the *subspitiensis* assemblage at Misool on the one hand and the *spitiensis-plicata* of Spiti and Kawhia on the other, is accentuated by Krumbeck's suggestion (1934, p. 445) that *Buchia subspitiensis* itself may be represented in the Spiti shales by Holdhaus' specimen figure 10 a-c on pl. 97.

It should be noted that the group of *B. subspitiensis* also seems to be represented on New Caledonia (*Aucella* cf. *leguminosa*, Piroutet, 1903), where its exact age, however, apparently is unknown.

Regarding the significance of the belemnites found mostly at or below the horizon with *Buchia subspitiensis*:—As has been said above belemnites of the group of *Belemnopsis gerardi* are characteristic members of the *Buchia* series throughout the Himalayan-Australasian realm. As early as 1911 Uhlig (p. 390) pointed out not only the importance of *Belemnopsis gerardi* in the Spiti sequence, but also the eastward extension of the *gerardi* fauna into the East Indian region, where the importance of canaliculate belemnites had become apparent after the publication of Boehm's first palaeontological results in 1905 and 1907. Later studies by Kruizinga (1921) and by Stolley (1929, 1934 b) have contributed materially to our knowledge of the East-Indian *Belemnopsis* fauna, their stratigraphical distribution and their relationships to the New Zealand forms described by Zittel in 1864, Hector in 1878, and Trechmann in 1923. Discussions by Spath (1927, 1933) have added valuable information to the relationships between the East-Indian species and those of the Spiti shales and of Kacch.

Stolley distinguishes two groups of canaliculate belemnites, viz., the group of *Belemnopsis canaliculata* and the group of *B. gerardi*. The former, characterised by a very narrow and sharp cut ventral groove, is but sparsely represented in the Himalayan-Australasian province, where the second group is found in abundance. The stratigraphical value of these belemnites has been much discussed. Stolley, in 1929, stressed their usefulness for correlation, if sufficient care in the determination of the species were taken, but their value for this purpose was doubted by Boehm as early as 1909 and again by Spath in 1927 and 1933. Whatever their importance may be in strata, where they occur in great number and variety, determinations on the basis of a few specimens, as in the case of the Australian finds, must be made with great care and should be accepted with due reservation. The Australian specimens belong to at least two species and are here compared with *Belemnopsis alfurica* (Boehm) and with *B. incisa* (Stolley). *B.* cf. *alfurica* is found in glauconitic sandstone immediately underlying the strata with *Buchia subspitiensis* in bore No. 3, whereas *Belemnopsis* cf. *incisa* occurs at a slightly higher level in bore No. 4 and at a somewhat lower horizon in bore No. 2.

In Misool, the typical species are characteristic of the Demú limestone, immediately above the Aucellen-Sandstein with *Buchia subspitiensis* and *B. subpallasi*, but it may be significant, that Stolley (1934 b) reports *Belemnopsis* cf. *alfurica* and *B.* cf. *incisa* from the Aucellen-Sandstein itself. If these specimens were conspecific with the Australian specimens mentioned here, the *Buchia-Belemnopsis* assemblage of Broome would be identical with that of the Aucellen-Sandstein of Misool. In Misool, *Belemnopsis gerardi* is younger than *B. alfurica*, but both species seem to be associated in the basal Belemnite bed of the Spiti shales, the age of which can be taken to be about Argovian or perhaps very slightly older (Spath 1933, pp. 661-662), but at any rate younger than the age assigned to the Aucellen-Sandstein by Wanner and by Stolley.

Taking all these facts into consideration it can be said that the fossiliferous strata in the Artesian bores at Broome most probably are an equivalent of the "Aucellen-Sandstein" of Misool. Attention must, however, be called to the fact that specimens of *Buchia*, doubtfully referred to *B. subspitiensis* and *B. subpallasi* have also been recorded from higher horizons in the Misool series, notably from the marly limestones of Lilintá and from the uppermost Fatjet shales. This in conjunction with the fact that the belemnites can be compared most closely with forms which are most common in horizons slightly above the Aucellen-Sandstein, may point to a slightly younger age of the strata concerned. The age of the strata should be approximately Oxfordian, most likely not early Oxfordian, but Divesian or Argovian. However, in view of the advanced stage of the *subspitiensis-subpallasi* fauna whose equivalents in the Himalayas are definitely post-Argovian and in New Zealand younger than the Oxfordian *malayomaorica* fauna, the possibility of a Kimmeridgian age of the fauna should not be altogether excluded.

CONCLUSION.

The differences between the development of the Jurassic in the western and in the eastern part of the East Indian Archipelago were fully set out by Wanner in 1925 and summarised and generalised by Umbgrove in 1938. Umbgrove recognised the existence of a geosynclinal basin which was in

existence throughout the Mesozoic in the eastern part of the archipelago which he termed the "Timor-East Celebes geosyncline" and it is with the Jurassic deposits of this geosyncline that the Jurassic strata of Broome have their closest relationships. In fact, it seems to be evident that the Australian occurrence forms the continuation of the Jurassic belt of the Timor-East Celebes geosyncline.

In a paper read at the Canberra meeting of the Australian and New Zealand Association for the Advancement of Science in January, 1939, I produced some evidence for the existence of a geosynclinal basin ("Westralian geosyncline") along the western margin of the Australia shield which came into existence not later than in Permian time and which I considered to be continuous with the Timor-East Celebes geosyncline of Umbgrove. The discovery of Jurassic beds with the typical facies of the Timor-East Celebes geosyncline in the northern part of this Western Australian trough gives further evidence of the similarities in the geological history of these two areas.

DESCRIPTION OF THE FAUNA.

Genus **SERPULA** Linné.

Serpula sp.

Plate I. Fig. 13.

The genus Serpula is represented by two specimens which are most similar to *Serpula convoluta* Goldfuss from the Middle Jurassic of Germany. The specimens occur in strata yielding *Buchia subspitiensis*. The better preserved specimen consists of slightly more than two volutions of the tube, of which the last one tends to become free from the preceding one. Where it is broken off the tube has attained a diameter of 5.7 mm. The wall of the tube consists of numerous fine concentric calcareous layers, and has a structure rather different from that described for Serpulidae by Gertrud Götz in 1931; in particular, no traces of the outer layer which is composed of parabolic transverse lamellae, can be discovered, but the great number of the concentric lamellae excludes the specimens from the gastropod family Vermetidae. The find is here recorded, because of the absence of comparable forms in contemporaneous East Indian deposits.

Occurrence: Broome, Artesian bore No. 3, 1,253-1,270 feet below sea-level.

Genus **BUCHIA** Rouillier.

Synonym: *Aucella* Keyserlingk, 1846.

The genus *Buchia* was established by Rouillier in Bulletin de la Société Impériale des Naturalistes de Moscou, vol. 18, p. 289, 1845, with *Avicula mosquensis* von Buch as the only species mentioned. This species, therefore, is the genotype by monotypy.

Buchia subspitiensis (Krumbeck).

Plate I, Figs. 1-7.

1934 *Aucella subspitiensis*, L. Krumbeck, Neu. Jahrb. etc., Beil.-Bd. 71 B, pp. 439-448, pl. 14, figs. 1-12, pl. 15, figs. 1-8.

1936 *Aucella* cf. *subspitiensis*, G. Wandel, Neu. Jahrb. etc., Beil.-Bd., 75 B, pp. 462-463.

Four left valves are available, two of them with the umbo destroyed, but all with fragments of the shell preserved and very little distorted.

A redescription of this species seems unnecessary in view of Krumbeck's exhaustive description to which the reader can be referred and which can be applied in almost every detail to the specimens here under consideration. One of the main features of the species is the obliquely truncated anterior end of the left valve. Also, the rather elongated shape and the short, stout, and not very strongly incurved umbo of the left valve are important.

The ornamentation consists mainly of concentric ridges differing in prominence in different specimens. The four specimens show all transitions from narrow, regularly spaced ridges which are only slightly raised above the general surface of the shell, to broader and stronger, somewhat irregularly spaced and more prominent folds. The same range of variation is also evident among the specimens from Misool when, e.g., the specimens figured by Krumbeck on pl. 14, figs. 1, 2 and 5, are compared.

Krumbeck described the radial ornamentation as very weak and the same can be said of the Australian specimens. Radial striae are well developed in the umbonal region of the left valve, where they are plainly visible for a distance of at least 5 mm. from the umbo. Farther on they become weaker and seem to fade out before the middle portion of the shell is reached. In one specimen, however, traces of the radial ornamentation are still recognizable behind the middle of the shell. These radial striae are not quite straight, but undulate in a somewhat irregular manner between the concentric ridges. The finely "granulated" surface, due to intersection of radial and fine concentric striae, which is illustrated by Krumbeck on pl. 15, figs. 7 and 8, is not visible in any of the Australian species.

The close relationships of this species with *Buchia bronni* Rouillier (see especially Lahusen, 1888, pl. 1, fig. 1) and with *B. spitiensis* Holdhaus have been fully discussed by Krumbeck and the importance of these similarities for the determination of the age of the strata has been discussed above. It may be added that among the boreal forms *B. lindstroemi* Sokolov from the Kimmeridgian and Volgian of Orenburg, Petchoraland, and Spitsbergen seems to be another closely related species (see Sokolov and Bodylevsky, 1931, p. 35). There is hardly any pre-Kimmeridgian species with which *B. subspitiensis* might be compared.

Occurrence: Broome, Artesian bore No. 3, 1,253-1,270 feet below sea-level.

Buchia subpallasi (Krumbeck).

Plate I, Figs. 8-12.

1934 *Aucella subpallasi*, L. Krumbeck, Neu. Jahrb., Beil. Bd. 71 B, pp. 450-454, pl. 15, fig. 11, pl. 16, figs. 1-10.

In addition to shell fragments one left valve and one right valve, both partly damaged, are available.

As in the case of the preceding species Krumbeck's description of *Buchia subpallasi* is exhaustive and nothing can be added to the knowledge of the species by the study of the limited Australian material. The species is characterised mainly by the long and acute umbo of the left valve which is strongly incurved with a slight forward twist. It is distinguished from the boreal *B. pallasi* as figured by Lahusen (1888, pl. 1) mainly by the greater prominence of the umbo and by the absence of the posterior ear of the left

valve which is slightly developed in the latter species. The Australian specimen agrees particularly well with the Misool specimens illustrated by Krumbeck on pl. 16, figs. 5 and 7.

The right valve, too, is in close agreement with the valves described from Misool. It is rather strongly convex in the dorso-ventral section and much less so in the longitudinal section. The byssus ear is small and has one radial fold as described by Krumbeck. The ornamentation of the left valve consists of weak concentric folds which are in some cases dichotomous, as also mentioned by Krumbeck. No traces of radial ornamentation are seen on the left valve; this is also absent in all the Misool specimens examined by Krumbeck, except one. The right valve has very fine concentric folds, much weaker than those of the left valve and apparently more irregularly spaced. There are also traces of very fine radial lines on the right valve. This valve resembles most closely that figured by Krumbeck on pl. 16, fig. 6. Its ornamentation is so faint that it can only be seen upon closer examination of the specimen. Krumbeck does not mention the presence of any radial ornaments in any of his Misool specimens.

Occurrence: Broome, Artesian bore No. 3, at 1,184 to 1,185 feet below sea-level. Perhaps also in bore No. 2, somewhere between 920 and 1,260 feet.

Genus **Belemnopsis** Bayle.

In spite of diligent efforts by Boehm (1905, 1907), Uhlig (1910), Spath (1927, 1933), Stolley (1929, 1934), and others to clarify the taxonomy of the Himalayan-East Indian species of *Belemnopsis* the systematic relationships of the many species established by Oppel, Waagen, Boehm, and Stolley are still far from being satisfactorily understood. All authors agree that at least some of the species of the *gerardi* group are indistinguishable unless a number of well preserved specimens is available. The following determinations of fragments obtained from the Artesian bores at Broome must, therefore, be accepted with every reservation.

Belemnopsis cf. **B. alfurica** (Boehm).

Plate I, Figs. 14-21.

cf. *Belemnites alfuricus*, J. Boehm, Palaeontogr., Suppl. Bd. IV., 1905, p. 56, pl. 8, figs. 4, 5.

cf. *Belemnopsis alfoericus*, P. Kruizinga, Jaarb. Mijnw. (1920), 1921, p. 8, pl. 2, figs. 1-3.

cf. *Belemnopsis alfurica*, E. Stolley, Pal. v. Timor, XXIX., 1929, p. 172.

Three fragments are here referred with reservation to this species with which it seems to agree more closely than with the closely related *Belemnopsis gerardi* Oppel (established in 1863, p. 273, described and figured in 1865). Unfortunately, Oppel when describing this species in detail in 1865, referred to it specimens now considered to belong to three different species. Stolley's concept of the species (1929, p. 151) was based on Oppel's specimen, fig. 3 (see Oppel, 1865, pl. 88), but Spath (1933, p. 662) has correctly rejected this choice of holotype, because this specimen was referred to the species by Oppel with reservation (explanation of pl. 88, fig. 3: "Bruchstück eines grösseren, vermuthlich zu Belemnites Gerardi gehörigen Exemplares."). Both Stolley and Spath regard Oppel's specimen fig. 2 as belonging to *Belemnopsis alfurica* (Boehm) and Oppel's specimen fig. 1 must, therefore, be selected as the holotype of *Belemnopsis gerardi*. Stolley

was of the opinion that this specimen should be referred to *B. aucklandica* Hauer, which is probably not correct, as already pointed out by Spath. If the holotypes of these two species should be found to be conspecific, the name *gerardi* would have priority over *aucklandica*, which was established in 1864 (Zittel, 1864, p. 29). From a comparison of the Australian specimens with Oppel's figures as well as with the improved cross-section of the holotype of *B. gerardi* reproduced by Boehm (1905, p. 55, text-fig. 20) and with Boehm's figures of *B. alfurica* (Boehm, 1905, pl. 8 and figures on p. 54) it appears that the Australian specimens differ from the holotype of *B. gerardi* in their more circular cross-section and in the deeper ventral groove and are, in this respect, more similar to Boehm's original specimens of *B. alfurica* as well as to Oppel's specimen fig. 2, which is regarded as a representative of the same species.

One specimen from bore No. 2, 1,300-1,305 feet (pl. I, figs. 17, 18) is a short cylindrical fragment of a guard with a lateral diameter of 14.3 mm. and a dorso-ventral diameter of 14.4 mm. The ventral groove is 2 mm. deep. No lateral lines are visible, but the sides are slightly worn. This specimen agrees well with specimens of *B. alfurica* figured by Boehm in 1905, but it is also similar to specimens which have been referred to *B. gerardi* by Uhlig (1910, pl. 93, figs. 9 a, b), by Kruizinga (1921, pl. 1, fig. 1) and by Stolley (1929, pl. 249, fig. 3).

A fragment of the lower part of a guard from bore No. 4, 1,250 feet (pl. I, figs. 14-16), has a dorso-ventral diameter of 14 mm. at its upper end and a lateral diameter of about 14 mm. (now smaller owing to slight wear of one side). The ventral groove is much shallower than in the preceding specimen; it is less than 1 mm. deep at the upper end and fades out at a distance of about 14 mm. from the tip of the guard. The lateral lines are clearly visible on one side of the guard, but disappear at about the same distance from the tip as the ventral groove. At this place (about 14 mm. from the tip) the dorso-ventral diameter of the guard is 9.2 mm., the lateral diameter 9.0 mm.

This specimen resembles *B. alfurica* Boehm in its slender shape; the guard of *B. gerardi* tapers more abruptly at its lower end. In this respect the specimen also bears close resemblance to the New Zealand species *B. aucklandica* Hauer (see Zittel, 1864, pl. 8, fig. 2) which is also reported from Jamdena and Timor in the East Indies (Stolley, 1929, p. 170). The lateral lines mentioned above are also known in *B. alfurica* Boehm, but they are likewise characteristic of *B. gerardi* as first noticed by Rothpletz in 1892 (p. 104) and confirmed by Boehm in 1905 (p. 56). They are, however, absent in *B. aucklandica* as expressively mentioned by Hauer (Zittel, 1864, p. 29).

In conclusion it can be said that the first two specimens mentioned above can be compared with either *B. gerardi* Oppel or with *B. alfurica* Boehm, whereas the third specimen resembles most closely *B. alfurica* and *B. aucklandica* Hauer. If these specimens represent one and the same species the relationships may be closest with *B. alfurica*.

This species has a wide distribution in the East Indies, where it is reported from Taliaboe, Mangoli, Misool, and Boeroe, and with reservation from Timor, Ceran, and East Celebes (Stolley, 1934 c). It also occurs in the Spiti shales of the Himalaya. In Misool, according to Stolley, it is

characteristic of the lower part of the Oxfordian sequence (see Table III). Its significance has been discussed in a preceding section.

Occurrence: Broome, artesian bore No. 2, 1,300-1,305 feet, bore No. 4 1,250 feet below sea-level.

Belemnopsis cf. **B. incisa** Stolley.

Plate I. Figs. 22, 23.

cf. *Belemnopsis incisa*, E. Stolley, Neu. Jahrb., Beil. Bd. 73 B., 1934, p. 51, pl. 2, fig. 2.

Neither the description nor the figures given by Stolley when he established this species are quite sufficient to determine exactly its relationships. He states that the guard most resembles medium-sized specimens of *B. gerardi*, but that it is clearly distinguished by the particularly sharp and deep cut ventral groove. He also states that, if the lateral sides are prolonged beyond the incision made by the ventral groove, a slightly oval cross-section is obtained, whereas a similar procedure in *B. gerardi* results in an almost circular cross-section.

Specimens obtained from bore No. 3, just below the strata with *Buchia subspitiensis*, seem to agree with this description. The best of the specimens (pl. I, figs. 22, 23) is the upper portion of a guard, with part of the alveolus, however, broken off, whose lateral diameter increases from 10.8 mm. to about 11.6 mm. at the lower end. The dorso-ventral diameter at the upper end is 10.6 mm. The ventral groove is very narrow and about 2 mm. deep, with steep sides. The cross-section agrees well with that described for *B. incisa* by Stolley. None of the specimens is well enough preserved to show whether or not lateral lines are developed.

Until better descriptions or actual specimens of *B. incisa* come to hand the specimens mentioned above must be referred to this species with reservation.

Occurrence: Broome, Artesian bore No. 3, 1,272 feet to 1,273 feet 9 inches, in glauconitic sandstone.

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EXPLANATION OF PLATE I.

All figures natural size, unless otherwise stated.

Figs. 1-7.—**Buchia subspitiensis** (Krumbeck). Broome, bore No. 3, 1,253-1,270 feet.

1, 2, left valve with slightly damaged umbo. No. 2/1912a.
7 enlarged portion of same specimen.
3, 4, 5, another left valve with rather regular concentric ornamentation (fig. 3 enlarged 1.5 X). No. 2/1912b.
6, large left valve with stronger irregular concentric ornamentation, No. 2/1913.

Figs. 8-12.—**Buchia subpallasi** (Krumbeck). Broome, bore No. 3, 1,184-1,185 feet.

8, 9, 11, left valve, No. 2/1910; 10, right valve, No. 2/1908; 12, byssus ear of right valve, enlarged 3 X, drawn from the external mould, No. 2/1909, left by specimen fig. 10 with portions of the ear still adhering to the mould.

Fig. 13.—**Serpula** sp. Broome, bore No. 3, 1,253-1,270 feet. No. 2/1911.

Figs. 14-21.—**Belemnopsis** cf. **B. alfurica (Boehm)**. Broome. (Figs. 14 and 20 show lateral lines.)

14, 15, 16, specimen from bore No. 4, 1,250 feet.
17, 18, specimen from bore No. 2, 1,300-1,305 feet. No. 2/1906.
19, 20, 21, another specimen from the same level.

Figs. 22, 23.—**Belemnopsis** cf. **B. incisa** Stolley. Broome, bore No. 3, 1,272-1,272 feet 9 inches. No. 2/1914.

All specimens are in the Geological Survey of Western Australia, except specimen figs. 14-16 which is in the collection of Mr. Bernard E. Bardwell, Broome, Western Australia.


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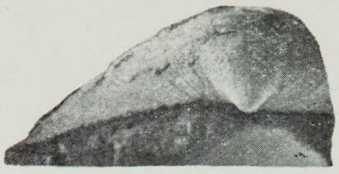
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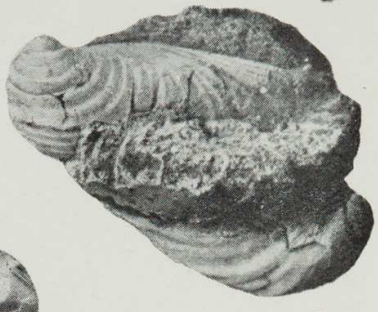
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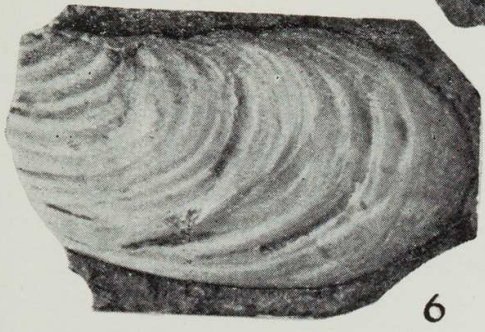
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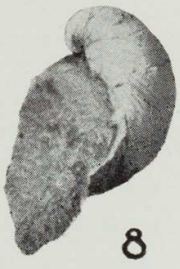
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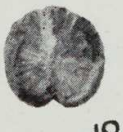
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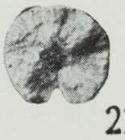
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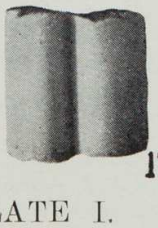
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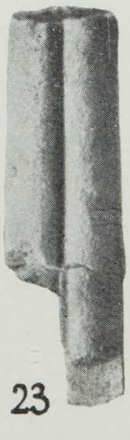
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PLATE I.